(19) **Europäisches Pat ntamt**

Eur pean Patent Office

Office européen des brevets

(11) Publication number : **0 656 706 A2**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number : 94308356.8

(22) Date of filing : 11.11.94

(51) Int. Cl.⁶ : **H04L 5/06**

---

(30) Priority : 12.11.93 JP 283582/93

(43) Date of publication of application :
07.06.95 Bulletin 95/23

(84) Designated Contracting States :
DE FR GB NL

(71) Applicant : KABUSHIKI KAISHA TOSHIBA
72, Horikawa-cho
Saiwai-ku
Kawasaki-shi Kanagawa-ken 210 (JP)

(72) Inventor : Sugita, Yasushi, c/o Intellectual
Property Div.
Toshiba Corp.,
1-1-1, Shibaura,
Minato-ku
Tokyo (JP)
Inventor : Ishikawa, Tatsuya, c/o Intellectual
Property Div.
Toshiba Corp.,
1-1-1, Shibaura,
Minato-ku
Tokyo (JP)
Inventor : Seki, Takashi, c/o Intellectual
Property Div.
Toshiba Corp.,
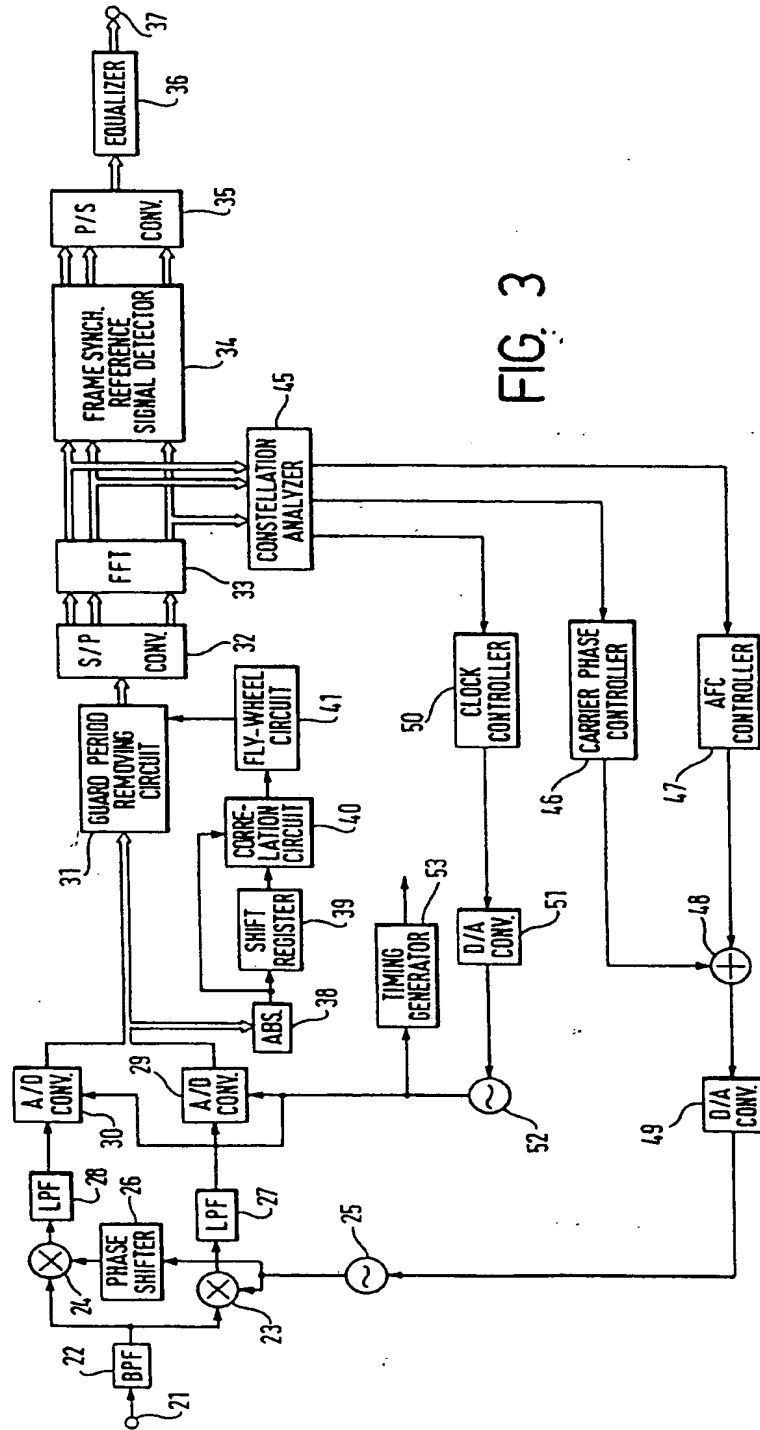1-1-1, Shibaura,
Minato-ku
Tokyo (JP)

(74) Representative : Muir, Ian R. et al
HASELTINE LAKE & CO.
Hazlitt House
28 Southampton Buildings
Chancery Lane
London WC2A 1AT (GB)

---

(54) Synchronisation of OFDM signals.

(57) The invention provides an OFDM synchronization demodulation circuit which includes a receiving circuit for receiving an orthogonal frequency division multiplex (OFDM) modulation signal, an orthogonal detection circuit for orthogonally detecting the OFDM modulation signal from the receiving circuit by using a restored carrier, a demodulation circuit for orthogonally demodulating the detected OFDM multiplex modulation signal from the orthogonal detection circuit through a sampling of the OFDM multiplex detection signal by using a restored clock. a constellation analyzing circuit for analyzing th constellation of d modulated symbols of predetermined carriers in the d - modulated OFDM multiplex signal signal, a carrier frequency deviation detection circuit for detecting a frequency deviation of the restored carrier based n a rotation of th constellation of th demodulated symbol det cted by th constellation analyzing circuit, a carrier restoration circuit responsive to the frequency deviation detected by the carrier frequency deviation detection circuit for controlling the restored carrier, a clock frequency deviation detection circuit for detecting a frequency deviation of the restored clock based on rotations of the constellations of at least two demodulated symbols detected by the constellation analyzing circui, and a clock restoration circuit responsive to the frequency deviation detected by the clock frequency deviation detection circuit for controlling the restored clock.

FIG. 3

The present inv ntion r lates to an OFDM synchronization demodulation circuit, and more particularly, to an OFDM synchronization demodulation circuit for obtaining a carrier synchronization and a clock synchronization from information signals.

In recent years, digital modulation techniques of high quality and high frequency utilizing efficiency have been developed for a transmission of video or audio signals. Particularly in the mobile radio communication, an adoption of orthogonal frequency division multiplex (hereinafter referred to as OFDM) modulation technique which is durable against a multiple path interference is now under the consideration. The OFDM is a system to disperse transmission digital data into multiple carriers (approximately 256 through 1024 carriers) (hereinafter simply referred to as multiple carriers) which are mutually orthogonal and to modulate each of them.

FIGURE 1 is a waveform diagram showing a typical frequency spectrum of the OFDM modulated wave.

As shown in FIGURE 1, the OFDM modulated wave is comprised of multiple carriers and each of the carriers has been, for instance, processed a QAM (quadrature amplitude modulation). Frequency pow-
r spectrum of the OFDM modulated wave in a channel is expressed by superposing a frequency spectrum of multiple QAM modulated carriers. Further, as all the frequency spectra of the carriers have same characteristics and the carriers are provided at relatively small and a same frequency interval, the waveform of the OFDM modulated wave resembles to a white noise.

By the way, the OFDM modulated wave is transmitted after it being orthogonally modulated. The OFDM modulated wave is obtained at a receiver section by synchronously demodulating it. In this case, it is considered that carriers for sync demodulation are restored by controlling oscillation output of an oscillator by transmitted wave. However, as the transmitted OFDM modulated wave is in a waveform resembled to white noise, it is not possible to make frequency detuning zero using the transmitted OFDM modulated wave. So, in a conventional OFDM sync demodulation circuit, it has been so designed that a frequency deviation is not generated by improving accuracy of an oscillator as could as possible. FIGURE 2 is a block diagram showing a conventional OFDM modulation/demodulation system including an OFDM sync demodulation circuit, which is discussed in "1992, Collection of Release Scheduled Open Research Theses of NHK Technical Research Institute", pp. 28-36.

In FIGURE 2, an OFDM modulation circuit 1 orthogonally modulates th OFDM modulated transmitted data using a carri r of frequency f1 and outputs the data from an adder 2, after OFDM modulating transmission data by an invers fast Fourier trans-

form circuit (hereinafter r ferred to as IFFT circuit). The OFDM modulated wave is input to an OFDM sync demodulator 3 via an adder 4. The OFDM modulated wave is supplied to a BPF 5 and after removing noise, it is supplied to multipliers 6, 7. The multiplier 6 is applied with in-phase axis restored a carrier with a frequency f1 from an oscillator 8 and performs an in-phase detection by multiplying with the OFDM modulated wave. Further, the phase of the carrier output from the oscillator 8 is shifted by - 90° by a phase shifter 9 and input to the multiplier 7 which in turn performs the orthogonal detection by multiplying the OFDM modulated wave.

The detection outputs from the multipliers 6, 7 are applied to A/D converters 12, 13 via low-pass filters (LPF) 10, 11, respectively and are converted to digital signals. The outputs of the A/D converters 12, 13 are applied to a fast Fourier transform (hereinafter referred to as FFT) circuit 14, where carriers are demodulated. The demodulated signal output from the FFT circuit is converted into serial data and output by a parallel/serial converter (hereinafter referred to as P/S converter) 15.

In a system, as shown in FIGURE 2, frequency deviations are prevented by highly promoting an oscillation accuracy of the oscillator 8 as described above. However, it is extremely difficult to maintain the oscillation accuracy, and furthermore, a high accuracy oscillator is expensive and it is hard to incorporate it to popular type receivers.

Further, as the OFDM modulated wave resmbles to a white noise, it is also difficult to maintain the frequency of restored clock in high accuracy using OFDM modulated wave. So, a method of inserting a reference signal may be adopted to obtain a clock synchronization. For instance, a reference signal such as a non-signal period (null symbol period) or a slot, etc., is added to data for every several tens of symbol periods. Thus, the demodulator section becomes possible to achieve a clock synchronization by detecting a reference signal contained in transmitted data. That is, by detecting a demarcation timing of a reference signal from the envelope of the modulated wave, the clock synchronization is obtained on the basis of the detected timing.

However, a sufficient accuracy cannot be obtained by the method of obtaining the clock synchronization based on a reference signal which is periodically transmitted. Further, the reference signal may be disturbed and detected erroneously. And in this case, the normal demodulation can not be executed for an extended period of time until a next reference signal is detected.

In cas of conventional OFDM sync demodulation circuits as described above, it was n ed d for using a highly accurate oscillator for obtaining the carrier synchronization. Thus the conv ntional circuits have a problem that it is difficult to adopt such a highly

accurate oscillator for popular type r c iv rs. Further, there was also a problem that in the method of restoring clocks by inserting a reference signal in transmission signal, the carrier synchronization is low in accuracy and weak against disturbance.

It is, therefore, an object of the present invention to provide an OFDM synchronization demodulation circuit which is capable of obtaining carrier synchronizations and clock synchronizations using OFDM modulated waves.

In order to achieve the above object, an OFDM synchronization demodulation circuit according to one aspect of the present invention includes a receiving circuit for receiving an orthogonal frequency division multiplex (OFDM) modulation signal, an orthogonal detection circuit for orthogonally detecting the OFDM modulation signal from the receiving circuit by using a restored carrier, a demodulation circuit for orthogonally demodulating the detected OFDM multiplex modulation signal from the orthogonal detection circuit through a sampling of the OFDM multiplex detection signal by using a restored clock, a constellation analyzing circuit for analyzing the constellation of demodulated symbols of predetermined carriers in the demodulated OFDM multiplex signal signal, a carrier frequency deviation detection circuit for detecting a frequency deviation of the restored carrier based on a rotation of the constellation of the demodulated symbol detected by the constellation analyzing circuit, a carrier restoration circuit responsive to the frequency deviation detected by the carrier frequency deviation detection circuit for controlling the restored carrier, a clock frequency deviation detection circuit for detecting a frequency deviation of the restored clock based on rotations of the constellations of at l ast two demodulated symbols detected by the constellation analyzing circui, and a clock restoration circuit responsive to the frequency deviation detected by the clock frequency deviation detection circuit for controlling the restored clock.

In the present invention, the orthogonal detection means obtains the detected output using the restored carriers. The demodulation means obtains the demodulated signals by sampling and demodulating the detected output of the orthogonal detection means using the restored clock. The demodulated symbols of the specific carriers of the demodulated signal are supplied to the constellation analyzing means for obtaining the constellation. If the frequency deviation of the restored carriers or that of the restored clocks is taken place, the phase of the demodulated symbols rotates. Further, as the phase rotating angle is based on th d viation of the r stored carrier frequ ncy or the restored clock frequency, th carrier restoring means obtains the carrier synchronization by controlling the r stored carriers based on the constellation of the restored symbols. In th phase rotation of the constellation based on the deviation of the restored

clock frequency, symbols are reversed or amount of rotation is different between different carriers. The clock restoring means 2 obtains the clock synchronization by controlling the restored clocks based on the constellation of more than two demodulated symbols.

Additional objects and advantages of the present invention will be apparent to persons skilled in the art from a study of the following description and the accompanying drawings, which are hereby incorporated in and constitute a part of this specification.

For a better understandings of the present invention and many of the attendant advantages thereof, reference will now be made by way of example to the accompanying drawings, wherein:

A more complete appreciation of the present invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIGURE 1 is a waveform diagram sowing a typical frequency spectrum of the OFDM modulated wave;

FIGURE 2 is a block diagram showing a conventional OFDM modulation/demodulation system;

FIGURE 3 is a block diagram showing one embodiment of an OFDM sync demodulation circuit according to the present invention;

FIGURE 4 is a block diagram showing a constellation analyzer shown in FIGURE 3;

FIGURE 5 is a block diagram showing another example of the constellation analyzer; and

FIGURES 6(a), 6(b) and 6(c) are explanatory diagrams for explaining the operation of the embodiment.

The present invention will be described in detail with reference to the FIGURES 3 through 6. Throughout the drawings, like or equivalent reference numerals or letters will be used to designate like or equivalent elements for simplicity of explanation.

FIGURE 3 is a block diagram showing one embodiment of an OFDM synchronization demodulation circuit according to the present invention. In FIGURE 3, the slim line arrow shows the channel of a real number signal and the wide line arrow shows the channel of a complex form signal.

OFDM modulated wave which has been received by a tuner (not shown) and converted into a baseband signal is input to an input terminal 21. The OFDM modulated wave is, for instance, QAM signal which was OFDM modulated, orthogonally modulated by specific frequency and transmitted at the transmitter section. Further, QAM signal is able to express symbols by an I-data corresponding to th real part of complex form signals and a Q-data corresponding to the imaginary part of the complex form signal. The base-band signal is applied to a band pass filt r (hereinafter referred to as BPF) 22, which remov s

noise outside the passing band and outputs the base-band signal to multipliers 23, 24.

An oscillator 25 outputs oscillation output (re-stored carriers) to a multiplier 23 and also, to a multi-plier 24 via a phase shifter 26 after its oscillation out-put frequency is controlled by a control signal from a digital/analog converter (hereinafter referred to as D/A converter) 49 which will be described later. The phase shifter 26 obtains a Q-axis oscillation output by shifting oscillation output (I-axis oscillation output) by 90°. The multipliers 23, 24 perform the orthogonal detection by multiplying the I-axis or Q-axis oscilla-tion output with the base-band signal, respectively. The in-phase axis detection output (I-signal) from the multiplier 23 is applied to an analog/digital converter (hereinafter referred to as A/D converter) 29 via a low-pass filter (hereinafter referred to as bPF) 27. Further, the orthogonal axis detection output (Q-signal) from the multiplier 24 is applied to another A/D converter 30 via an LPF 28. LPFs 27, 28 remove harmonic wave component of I-signal or Q-signal, respectively. The A/D converters 29, 30 are supplied with an operating clock from an oscillator 52 which will be described lat-er, convert signals which are input at a sampling in-terval based on the operating clock into discrete val-ues and output them to an absolute value circuit 38 and a guard period removing circuit 31.

The absolute value circuit 38 obtains an absolute value of amplitude of OFDM modulated wave and out-puts it to a shift register 39 and a correlator 40. By the way, as transmission data is modulated by dividing it into several hundred through several thousand carri-rs in the OFDM, modulation symbol rate of each car-ri r becomes extremely low and a period of one sym-bol becomes extremely long. Therefore, it is hardly af-fected by a delay time by reflecting waves. Further-more, the effect of multi-path interference can be re-moved effectively when a guard period is set in front of an available symbol period. The guard period is produced by cyclically copying the terminal section of the available symbol period. If a multi-pass interfer-ence delay time is provided in the guard period, it is possible to prevent inter-symbol interference by an d layed adjacent symbol by demodulating only sig-nals of the available symbol period during the demod-ulation.

The shift register 39 outputs the output of the ab-solute value circuit 38 to the correlator 40 by delaying it for a time over the available symbol period and the guard period. Then, it becomes possible to output the guard period of the delay signal from the shift register 39 at the timing when the output of the absolute value circuit 39 is in the terminal section of the available symbol p riod. Since the guard period is a copy of the terminal section of the available symbol period, the correlation between th   utput of the absolute value circuit 38 and the output of the shift register 39 be-comes extr mely high at th timing of the guard per-

iod. Further, as OFDM modulated wav is a noisy sig-nal, the correlation between the output of the abso-lute value circuit 38 and its delay signal is small. The correlator 40 obtains the correlation between two in-puts and outputs a timing signal showing that the re-sult of correlation exceeds the specific threshold val-ue to a flywheel circuit 41. The timing signal is gen-erated from the correlator 40 for every OFDM symbol. The flywheel circuit 41 is reset by the timing signal from the correlator 40 and outputs a guard timing sig-nal of a fixed cycle based on the timing signal cycle to the guard period removing circuit 31.

The guard period removing circuit 31 removes the guard period of OPDM modulated waves (I-signal and Q-signal) and extracting the available symbol period signal, outputs it to a S/P (serial/parallel) converter 32. The S/P converter 32 converts the input serial data into parallel data and outputs the parallel data to an FFT circuit 33.

The FFT circuit 33 performs the FFT process by regarding inputs of an I-signal and a Q-signal as the real part and the imaginary part of a complex form sig-nal, respectively. The synchronization demodulation of respective carriers is performed by the FFT proc-ess. That is, the real part and the imaginary part of the complex form signal output which was FFT processed by the FFT circuit 33 become the I-data and the Q-da-ta which are demodulated symbols of respective car-riers. These OFDM demodulated signals are applied to a frame sync/reference signal detector 34. The frame sync/reference signal detector 34 passes and outputs the OFDM demodulated signals to a P/S (par-allel/serial) converter 35 and by extracting frame sync signals and equalized reference signals from the OFDM demodulated signals, outputs them to an equalization circuit 36.

The P/S convertor 35 converts the OFDM de-modulated signals which have become QAM signals for respective carriers after demodulated by the FFT circuit 33 into serial data and outputs to the equaliza-tion circuit 36. The equalization circuit 36 equalizes the input data using a reference signal and outputs through an output terminal 37.

In this embodiment, the demodulated output of the FFT circuit 33 is also supplied to a constellation analyzer 45 in order to obtain carrier synchronization and clock synchronization. FIGURE 4 is a block dia-gram showing one example of the constellation ana-lyzer in FIGURE 3.

Demodulated symbols of specific carriers from the FFT circuit 33 are supplied to the constellation analyzer 45. Further, to make the explanation simple, for instance, only demodulated symbols of two carri-ers of minimum and maximum frequ ncies are sup-plied to the constellation analyzer 45 in PIGURE 4. Thes demodulated symbols of two carriers of mini-mum and maximum frequencies are supplied to phase comparators 61, 62. respectively. The constel-

lation analyzer 45 detects th phase rotation of OFDM demodulated signals by analyzing the constellation of demodulated symbols of specific carriers of the respective OFDM demodulated signals. The phase comparators 61, 62 compare the constellation phases of minimum and maximum frequency carriers with specific reference phase and outputs phase differences $\phi 1$, $\phi 2$ to absolute value circuits 63, 64. Further, these phase differences $\phi 1$ and $\phi 2$ are also input to a sign judging circuit 65.

Now, it is assumed that the restored carrier frequency of the oscillator 25 for orthogonal detection (see FIGURE 3) does not coincide with OFDM demodulated wave carrier frequency. In this case, phases of detected outputs of the multipliers 23, 24 rotate. The phase comparators 61, 62 detect the phase rotation. The absolute value circuits 63, 64 obtain absolute values of the input phase differences $\Phi 1$ and $\Phi 2$ and outputs them to a mean value circuit 66, which in turn obtains a mean value of two inputs and outputs it to a sign adding circuit 67 as a representative value of a carrier rotation angle. Further, the absolute value circuits 63, 64 and the mean value circuit 65 are not always necessary and for instance, an oscillator which outputs "1" as a representative value to express a rotation angle of carrier may be used. FIGURE 5 is a block diagram showing another example of the constellation analyzer and shows an example where a signal generator 73 is used instead of the absolute value circuits 63, 64 and the mean value circuit 66, as shown in FIGURE 4. The signal generator 73 always outputs, for instance, "1" as a representative value of the rotation angle.

Further, if a difference between a restored reference carrier frequency for detection operation and a carrier frequency of received signal is integer multiple of a frequency difference between carriers of OFDM demodulated waves, the phase of detected output rotates by 360°, and therefore, the outputs of the phase comparators 61, 62 become zero (0). That is, a phase difference between adjacent carriers is 360° and if sampling frequencies of the A/D converters 29, 30 are proper, that is, they are clock synchronized, the phase rotations of carriers coincide with each other and the outputs of the phase comparators 61, 62 become nearly the same values. For instance, if a phase difference $\phi 1$ is a positive value, a phase difference $\phi 2$ also becomes a positive value, while if the phase difference $\phi 1$ is a negative value, the phase difference $\phi 2$ also becomes a negative value.

On the other hand, even when no clock synchronization has been attained and sampling frequency of OFDM demodulated wave is not proper, the phase of OFDM demodulat d signal rotates. In this case, when assuming that r stored carrier frequency coincides with carrier fr quency of OFDM demodulat d wave, the phas difference $\phi 1$ of th lower frequency carrier and th phase difference $\phi 2$ at the higher frequency

carrier are reversed bounded by the carrier of carrier frequency 0. For instance, when the phase difference $\phi 1$ is positive, the phase difference $\phi 2$ will become negative and if the phase difference $\phi 1$ is negative, the phase difference $\phi 2$ will become positive.

The sign judging circuit 65 judges whether the phase rotation of carriers is due to deviation of carrier synchronization or deviation of clock synchronization by judging signs of phase differences $\phi 1$ and $\phi 2$. That is, if $\phi 1 > \phi 2$ and $\phi 1 < \phi 2$, the sign judging circuit 65 judges that no clock synchronization has been attained and outputs "-2" and "-1", respective as the judging result A. If $\phi 1$, $\phi 2 > 0$ and $\phi 1$, $\phi 2 < 0$, the sign judging circuit 65 judges that no carrier synchronization has been attained and outputs "0" and "1", respectively as the judging result A. These judging results A are supplied to the sign adding circuit 67 and a switch 68.

The sign adding circuit 67 decides the direction to control frequency deviation by adding a positive or negative sign to a representative value of the rotating angle from the mean value circuit 66 based on the judging result A. The output of the sign adding circuit 67 is supplied to the switch 68. The switch 68 outputs the output of the sign adding circuit 67 to a clock controller 50 if the judging result A is negative and outputs the output of the sign adding circuit 67 to the carrier phase controller 46 and the AFC controller 47 if the judging result A is positive.

In FIGURE 3, the clock controller 50 is supplied with the output of the constellation analyzer 45 and outputs a control signal to make the outputs of the phase comparators 61, 62 zero (0) to a D/A converter 51. The D/A converter 51 converts the input control signal into an analog signal and supplies it to an oscillator 52. The oscillator 52 controls oscillation frequency based on the control signal and generating a clock for OFDM modulated wave sampling, applies it to the A/D converters 29, 30. Thus, it becomes possible to obtain clock synchronization. Further, the clock from the oscillator 52 is also applied to a timing generator 53. The timing generator 53 generates a timing signal in synchronism with the sampling clock for parts in the demodulation circuit.

An AFC controller 47 is supplied with the output of the constellation analyzer 45 and generating an AFC control signal to bring restored carrier frequency in coincidence with carrier frequency, applies it to an adder 48. A carrier phase controller 46 generates a phase sync control signal to bring restored carrier phase in coincidence with carrier phase based on the output of the constellation analyzer 45 and outputs it to the adder 48. The adder 48 adds up the AFC control signal and the phas sync control signal and outputs the added result to a D/A converter 49. The D/A converter 49 converts the added result into an analog signal and applies it to the oscillator 25. The oscillator 25 is controlled for oscillation by the output of the D/A

converter 49 and outputs r stored carriers which co-
incide with carrier frequency. Thus, the carrier syn-
chronization can be attained.

Next, the operation of the embodiment construct-
d as described above will be explained with refer-
nce to the explanatory diagram of S 6(a) through
6(c). In FIGURES 6(a) through 6(c), frequencies are
indicated on the X-axis and amplitudes of carriers
from the FFT circuit 33 are indicated on the Y-axis.
The output of the FFT circuit will be obtained as de-
scribed below.

OFDM modulated waves transmitted via a trans-
mission line (not shown in FIGURE 3 are received by
a tuner (not shown), converted into base-band signal
and supplied to the BPF 22 via the input terminal 21.
The BPF 22 outputs the base-band signal after re-
moving noise contained in the signal to the multipliers
23, 24. The multipliers 23, 24 are supplied with in-pha-
se axis restored carriers or orthogonal axis restored
carriers and performs the orthogonal demodulation of
the signal. In-phase axis signal from the multiplier 23
is applied to the A/D converter 29 via the LPF 27 while
the orthogonal axis signal from the multiplier 24 is ap-
plied to the A/D converter 30 via the LPF 28. The A/D
converters 29, 30 convert the in-phase axis signal
and the orthogonal axis signal into digital signals us-
ing the restored clock and output them to the guard
period removing circuit 31.

On the other hand, OFDM modulated waves from
the A/D converters 29, 30 are supplied to the absolute
value circuit 38 and absolute values of the OFDM
modulated waves are supplied to the shift register 39
and the correlator 40. The shift register 39 applies the
OFDM modulated waves to the correlator 40 by delay-
ing for the available symbol period. As a result, the re-
lation between the OFDM modulated waves and its
delay signals become high and the output signal level
of the correlator 40 becomes high at the timing of the
terminal section of the available symbol period. The
flywheel circuit 41 generates a guard timing signal for
every OFDM modulating wave by comparing the out-
put level of the correlator 40 with a specific threshold
value and outputs it to the guard period removing cir-
cuit 31. The guard period removing circuit 31 removes
a guard period using the guard timing signal.

The OFDM modulated waves with the guard per-
iod thus removed and the available symbol period
only extracted are supplied to the S/P convertor 32
where they are converted into parallel data. The FFT
circuit 33 will FFT process the OFDM modulated
waves converted into parallel data. As a result, the
OFDM modulated signal from the FFT circuit 33 is
supplied to the frame sync/reference signal detector
34, wher th frame sync signal is xtract d and at
the same time, the r fer nc signal for wav form
equalization is extracted. The OFDM modulat d sig-
nal is conv rted into serial data by th P/S converter
35, and its waveforms are equalized in the equaliza-

tion circuit 36 and output through the output terminal
37.

In this embodiment, the OFDM demodulated sig-
nal from the FTT circuit is used to obtain the clock
synchronization and the carrier synchronization. The
OFDM demodulated signal from the FFT circuit 33 is
supplied to the constellation analyzer 45. Now, it is
assumed that, for instance, minimum and maximum
frequency carriers out of the OFDM modulated wave
carriers, as shown in FIGURE 6(a), are supplied to the
constellation analyzer 45. Further, as shown in FIG-
URE 6(a), frequencies of these maximum and mini-
mum frequency carriers are fs/2 and - fs/2, respec-
tively. The phase comparators 61, 62 of the constel-
lation analyzer 45 compare the phases of maximum
and minimum frequency carriers with the specific ref-
erence phases.

Now, it is assumed that the OFDM modulated
wave carrier frequency and the restored carrier fre-
quency of the oscillator 25 do not coincide with each
other. Then, the phase of orthogonally demodulated
OFDM modulated wave rotates and carriers of the
OFDM demodulated signal from the FFT circuit are
shifted from the normal carrier frequency indicated
by the broken line on the frequency axis, as shown by
FIGURE 6(b). That is, all carriers of the OFDM de-
modulated signal are shifted from the normal position
on the frequency axis by Δf. The amount of shift Δf is
a frequency difference between the OFDM modulat-
ed wave carrier and restored carrier.

When the constellation of the OFDM demodulat-
ed symbols is analyzed under the state, it is seen that
carriers rotates at a phase angle corresponding to the
amount of shift Δf. That is, if carriers haven't been
synchronized, all carriers rotate at the same phase
angle. Accordingly, the outputs of the phase compar-
ators $\phi 1$, $\phi 2$ become the same polarity. The sign judg-
ing circuit 65 outputs "0" as the judging result A when
judged that the phase differences $\phi 1$, $\phi 2$ are at posi-
tive polarity and "1" when judged that they are at neg-
ative polarity. On the other hand, after the phase dif-
ferences $\phi 1$, $\phi 2$ are supplied to the absolute value cir-
cuit 63, 64 for obtaining absolute values, a mean val-
ue of them is obtained by the mean value circuit 66.
The mean value is supplied to the sign adding circuit
67 as a representative value of carrier phase angle.
The sign adding circuit 67 adds a sign showing the ad-
justing direction of restored carrier frequency to the
representative value of phase angle based on the
judging result A and outputs the added result to the
switch 68. In this case, the switch 68 outputs the out-
put of the sign adding circuit 67 to the carrier phase
controller 46 and the AFC controller 47.

The carrier phas controller 46 and the AFC con-
troller 47 generate th phase sync control signal and
the AFC control signal, respectively based on the out-
put of th constellation analyzer 45. These signals ar
added up in the adder 48, converted into an analog

signal by th D/A convert r 49 and supplied to the os-
cillator 25. Thus, the oscillation output of the oscillator
25 is controlled so that the restored carrier frequency
coincides with the carrier frequency of the OFDM
modulated wave.

Here, it is assumed that no clock synchronization
has been attained and sampling frequency of the A/D
converter is lower than proper frequency. Then, the
carrier phase of OFDM demodulated signal rotates.
Now, it is assumed that carrier synchronization has
been attained and the phase of frequency 0 carrier of
the OFDM demodulated signal does not rotate and
the frequency is proper. In this case, carriers other
than those of frequency 0 out of the OFDM demodu-
lated signal are generated while shifted from proper
carrier frequency, as shown in FIGURE 6(c). That is,
while shift of frequency 0 carriers is Δf = 0, carriers
at the higher frequency is shifted from normal fre-
quency and amount of shift Δf becomes large as fre-
quency becomes high. On the other hand, carriers at
the lower frequency are shifted to the negative diction
rather than to the normal frequency and in this case,
amount of shift Δf also becomes large as frequency
becomes low.

That is, if the frequency of the restored clock is
shifted, the shifting direction of the carrier frequency
becomes different at the higher frequency and the
lower frequency bounded by the frequency 0 carrier.
Therefore, the constellations of demodulated sym-
bols of minimum and maximum frequency carriers
are observed in the reverse directions, respectively.
For instance, assuming that the maximum frequency
carriers 81, as shown in FIGURE 6(c), is rotating
clockwise, the minimum frequency carriers 82 rotate
counterclockwise. That is, the phase rotating direc-
tions of the higher frequency carriers and the lower
frequency carriers differ from that of frequency 0 car-
riers.

If the phase differences Φ1, Φ2 are different
signs, the sign judging circuit 65 judges that restored
clock frequency has been shifted. That is, the sign
judging circuit 65 outputs "- 2" as the judging result A
if φ1 > 0 > φ2 and "- 1" as the judging result A if φ1 <
0 < φ2. The sign adding circuit 67 adds a sign showing
the adjusting direction of restored clock frequency to
a representative value of phase angle based on the
judging result A and outputs the added result to the
switch 68. Then, the switch 68 outputs the output of
the sign adding circuit 67 to the clock controller 50.

If two higher frequency carriers or two lower fre-
quency carriers than frequency 0 carrier are used as
carriers to be supplied to the constellation analyzer
45, phas differ nces φ1, φ2 will becom the same
sign. How v r, as their values are differ nt ach
oth r, th shift of restored clock frequency can be de-
tect d.

The clock controller 50 generates a control signal
for controlling restored clock frequency based on the

output of the constellation analyzer 45. The control
signal is converted into an analog signal by the D/A
converter 51 and is supplied to the oscillator 52. Thus,
the oscillation output of the oscillator 52 is controlled
and restored clock frequency conforms to proper
sampling frequency of the OFDM modulated wave.
The clock synchronization is thus attained.

Further, the amount of shift by the carrier syn-
chronization is sufficiently larger than the amount of
shift by the clock synchronization and therefore, even
when both of the carrier synchronization and the
clock synchronization have not been attained, both
the carrier and the clock synchronizations can be at-
tained by first obtaining the carrier synchronizing car-
rier and then, the clock synchronization based on the
phase differences φ1, φ2 of the phase comparators
61, 62.

As described above, in this embodiment the
phase rotation of demodulated symbols from the FFT
circuit 33 is obtained by the constellation analysis and
detecting the carrier synchronization shift and the
clock synchronization shift, restored carriers and
clocks are controlled based on the detected result.
Thus, the carrier and clock synchronizations are at-
tained based on information signals only and it is pos-
sible to attain the carrier and clock synchronizations
firmly at high speed without using an expensive os-
cillator and without inserting a special reference sig-
nal and to achieve OFDM demodulation which is
strong against disturbance.

As described above, the present invention has an
effect to achieve carrier and clock synchronizations
using OFDM modulated wave.

While there have been illustrated and described
what are at present considered to be preferred em-
bodiments of the present invention, it will be under-
stood by those skilled in the art that various changes
and modifications may be made, and equivalents
may be substituted for elements thereof without de-
parting from the true scope of the present invention.
In addition, many modifications may be made to
adapt a particular situation or material to the teaching
of the present invention without departing from the
central scope thereof. Therefor, it is intended that the
present invention not be limited to the particular em-
bodiment disclosed as the best mode contemplated
for carrying out the present invention, but that the
present invention includes all embodiments falling
within the scope of the appended claims.

The foregoing description and the drawings are
regarded by the applicant as including a variety of in-
dividually inventive concepts, some of which may lie
partially or wholly outsid the scope of some or all of
the following claims. Th fact that th applicant has
chosen at the time of filing of the present application
to restrict the claimed scope of protection in accor-
dance with the following claims is not to be taken as
a disclaimer or alternative inventive concepts that are

included in the contents of the application and could b defined by claims differing in scope from the following claims, which different claims may be adopted subsequently during prosecution, for example, for the purposes of a divisional application.

Claims

1. An OFDM synchronization demodulation circuit comprising:

    receiving means for receiving an orthogonal frequency division multiplex (OFDM) modulation signal;

    orthogonal detection means for orthogonally detecting the OFDM modulation signal from the receiving means by using a restored carrier;

    demodulation means for orthogonally demodulating the detected OFDM multiplex modulation signal from the orthogonal detection means through a sampling of the OFDM multiplex detection signal by using a restored clock;

    constellation analyzing means for analyzing the constellation of demodulated symbols of predetermined carriers in the demodulated OFDM multiplex signal signal;

    carrier frequency deviation detection means for detecting a frequency deviation of the restored carrier based on a rotation of the constellation of the demodulated symbol detected by the constellation analyzing means;

    carrier restoration means responsive to the frequency deviation detected by the carrier frequency deviation detection means for controlling the restored carrier;

    clock frequency deviation detection means for detecting a frequency deviation of the restored clock based on rotations of the constellations of at least two demodulated symbols detected by the constellation analyzing means; and

    clock restoration means responsive to the frequency deviation detected by the clock frequency deviation detection means for controlling the restored clock.

2. An OFDM synchronization demodulation circuit as claimed in claim 1, characterized in that the carrier restoration means detects the frequency deviation of the restored carriers based on that the constellations of more than one demodulated symbol rotate in the same direction, and the clock restoration means detects the frequency deviation of restored clocks based on that the constellations of more than one d modulated symbol rotate in the oposit direction with each other or that there is a difference between the rotations.

3. Method for demodulating an OFDM synchroniza-

tion, comprising th steps of:

    receiving an orthogonal frequency division multiplex (OFDM) modulation signal;

    orthogonally detecting the received OFDM modulation signal by using a restored carrier;

    orthogonally demodulating the detected OFDM multiplex modulation signal through a sampling of the OFDM multiplex detection signal by using a restored clock;

    analyzing the constellation of demodulated symbols of predetermined carriers in the demodulated OFDM multiplex signal signal;
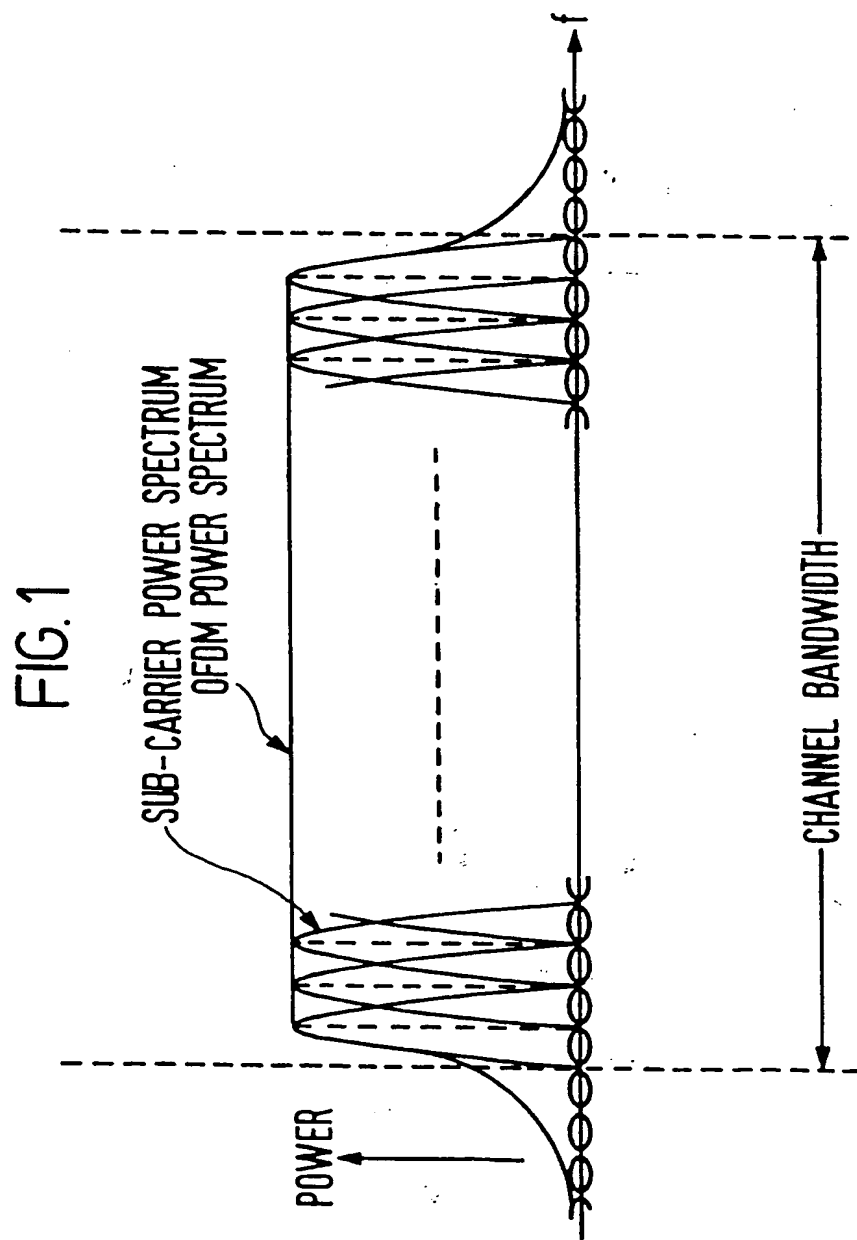
    detecting a frequency deviation of the restored carrier based on a rotation of the analyzed constellation of the demodulated symbol;
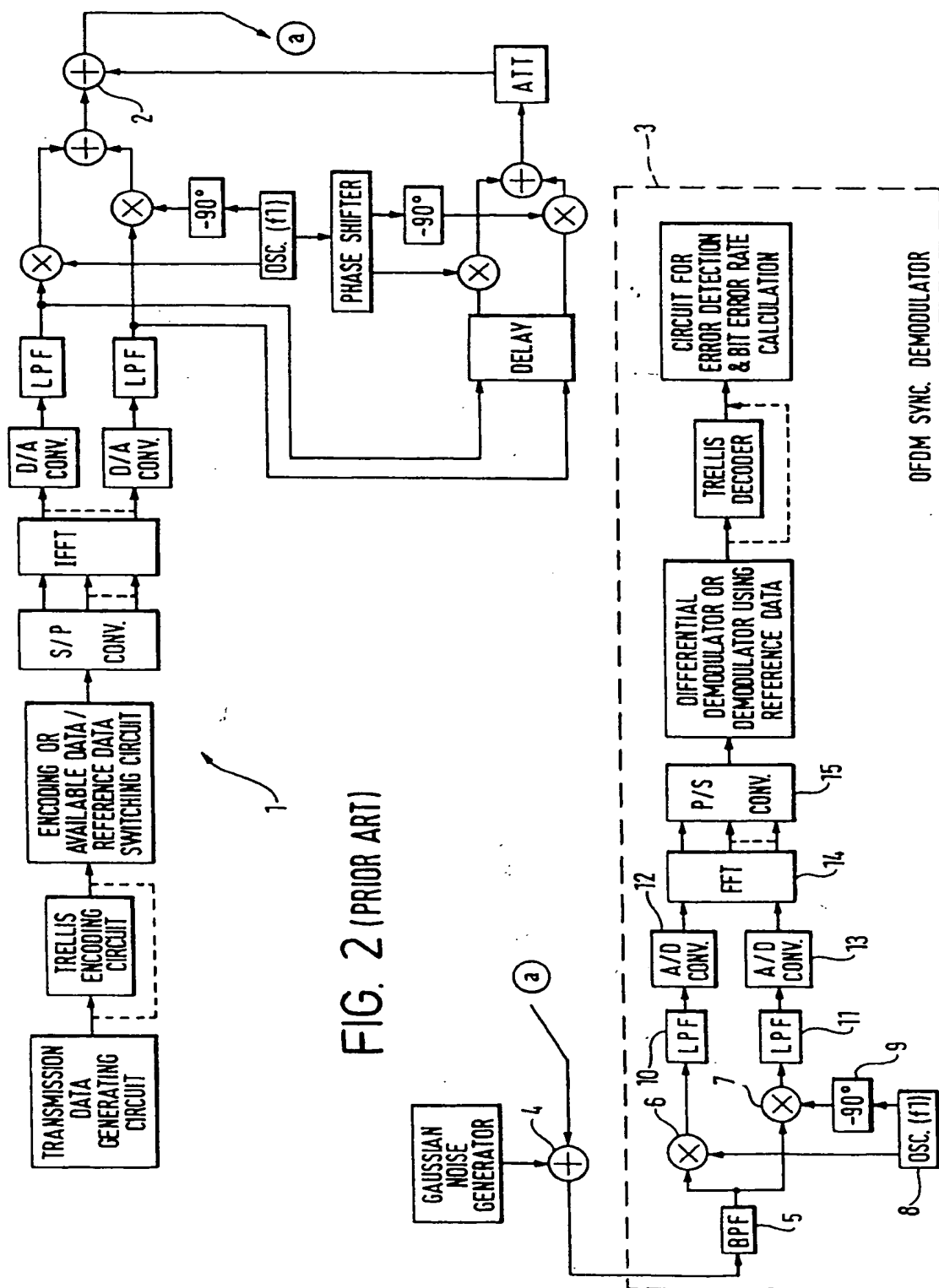
    controlling the restored carrier in response to the detected frequency deviation;

    detecting a frequency deviation of the restored clock based on a rotation of the analyzed constellation of the demodulated symbol; and

    controlling the restored clock in response to the detected frequency deviation.

4. A method as claimed in claim 3, wherein the frequency deviation of the restored carriers is detected based on that the constellations of more than one demodulated symbol rotate in the same direction, and the frequency deviation of restored clocks is detected based on that the constellations of more than one demodulated symbol rotate in the oposite direction with each other or that there is a difference between the rotations.
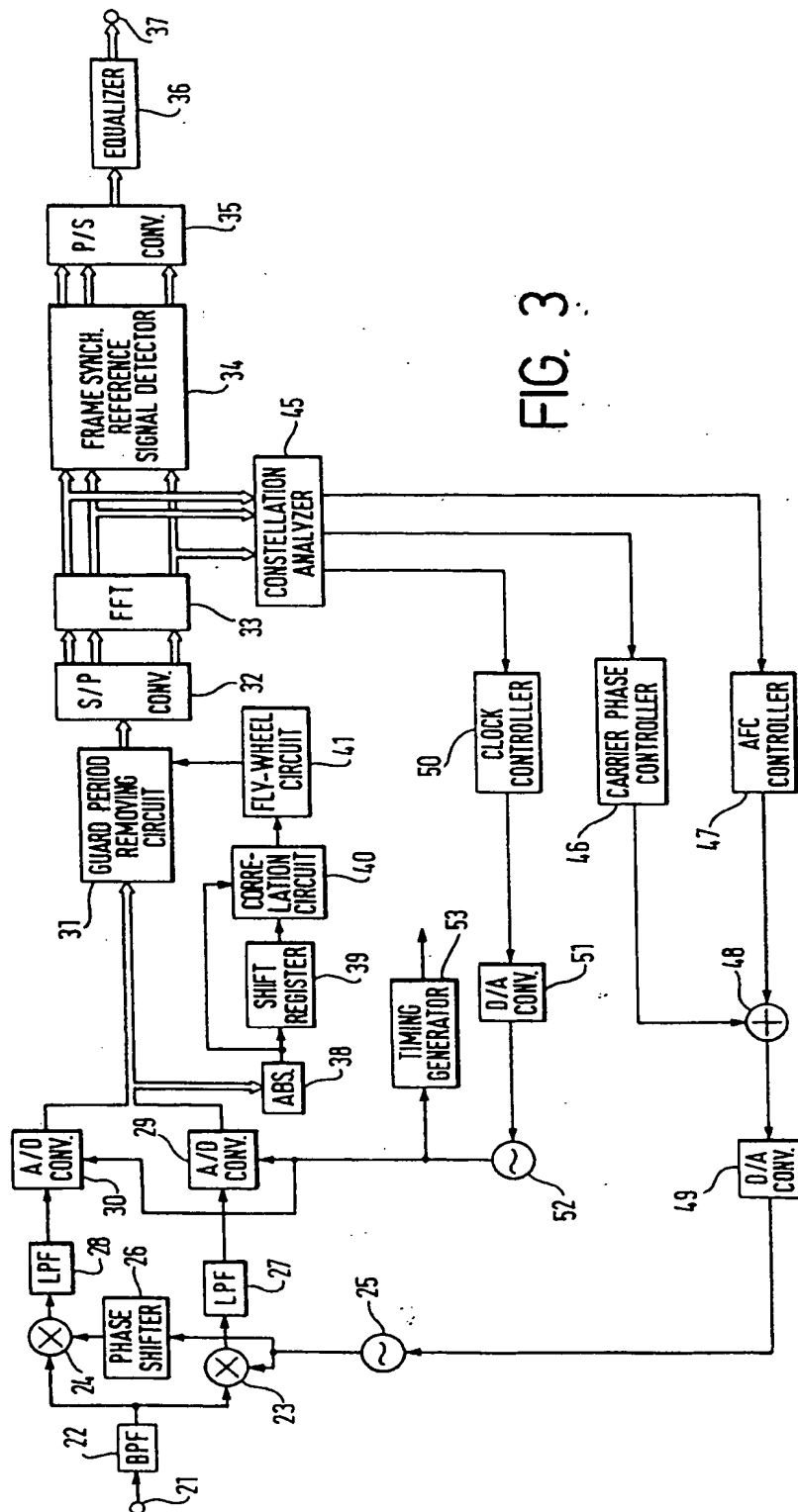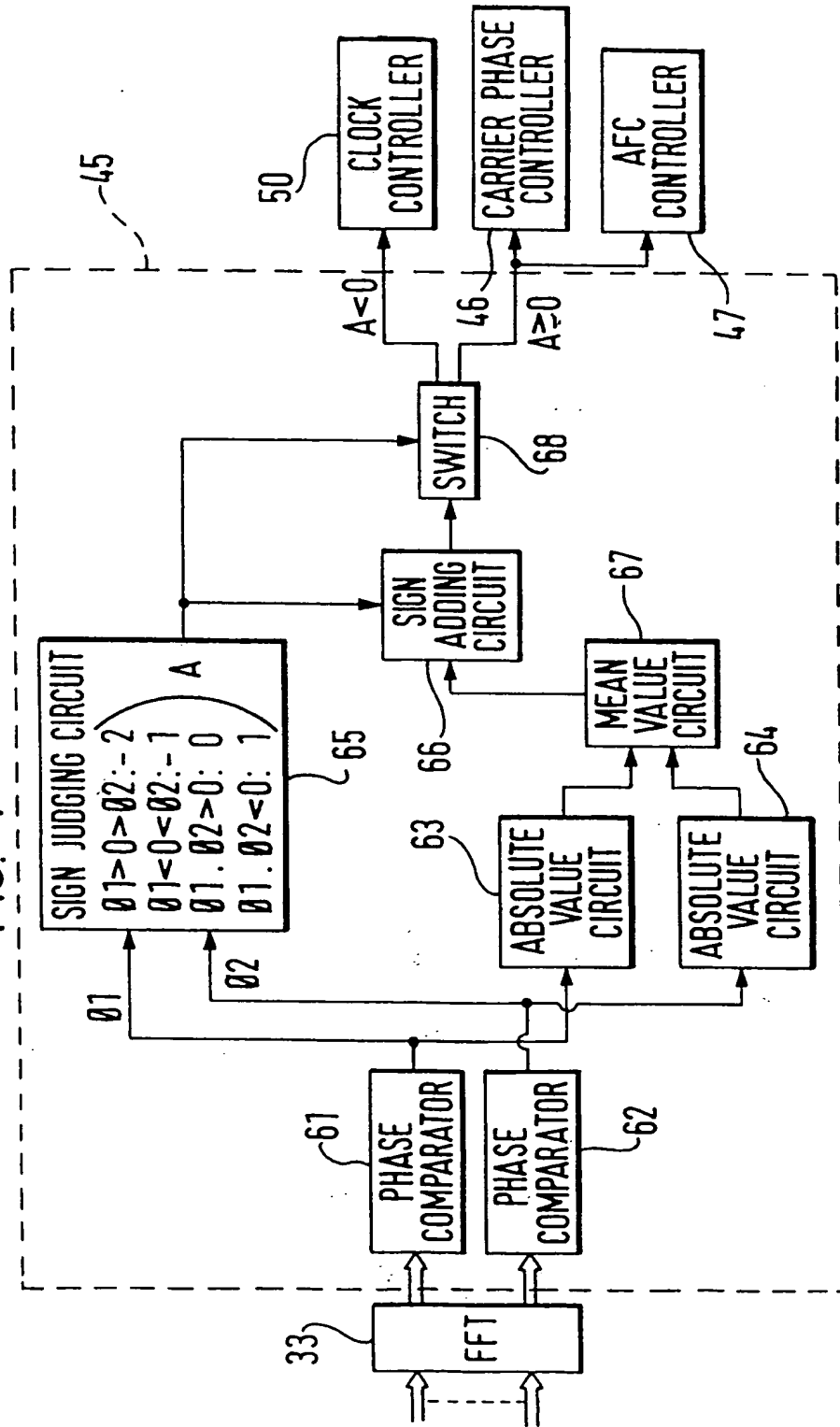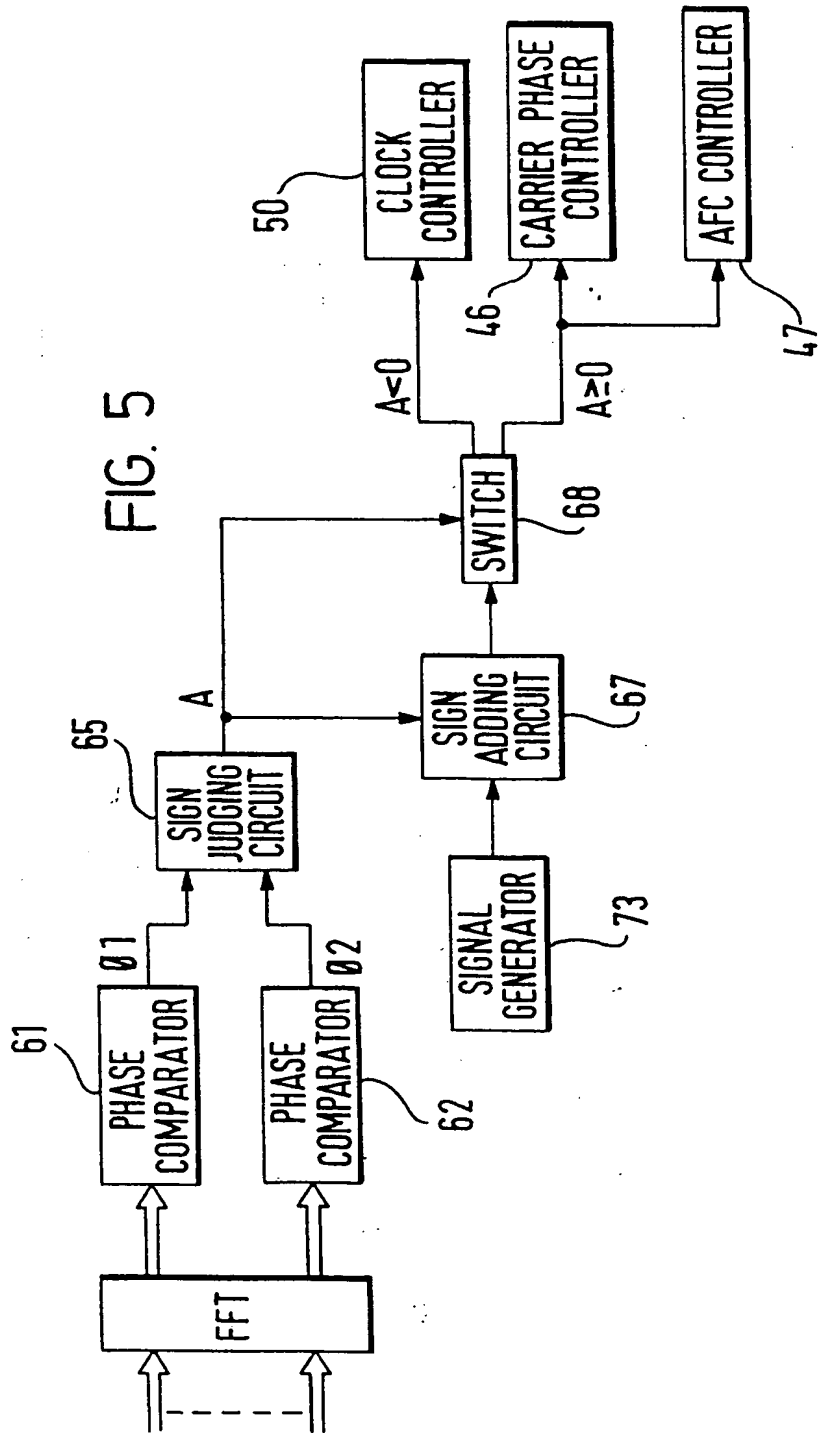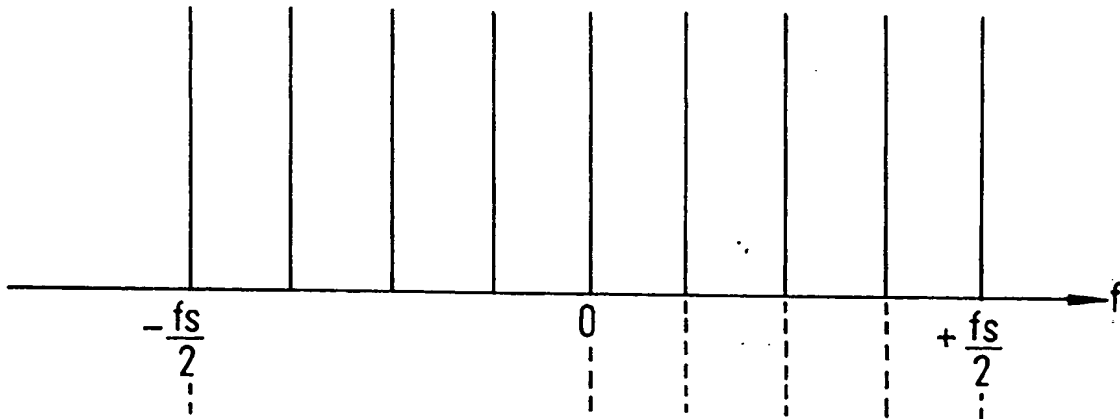
FIG.1

FIG. 2 (PRIOR ART)

FIG. 3

FIG. 4

FIG. 5

FIG. 6(a)

f

$-\dfrac{fs}{2}$ 0 $+\dfrac{fs}{2}$

FIG. 6(b)

$\triangle f$

f

FIG. 6(c)

$\triangle f$

82

81

f